CO-PRODUCING HYDROGEN AND POWER BY BIOMASS GASIFICATION

BACKGROUND OF INVENTION

[0001] The present invention relates generally to hydrogen-based energy generation systems and more particularly to co-production of hydrogen and power utilizing biomass gasification process.

[0002] In current energy scenarios, global energy infrastructure is rapidly transitioning from conventional "fossil fuel-based power production systems" to "hydrogen-based power production systems." Hydrogen production for these hydrogen-based power production systems may desirably be maintained utilizing renewable energy sources. In implementation, maintaining an uninterrupted supply of renewable energy derived from renewable energy sources is a potential issue because most renewable energies are intermittently available during a period when environmental conditions are favorable or appropriate for producing them.

[0003] Generally, in conventional approaches, alternative supply of hydrogen during non-availability of these renewable energies may be envisaged by transporting the hydrogen to these hydrogen-based power production systems from a hydrogen-storage system. In operation, certain concerns pertaining to these hydrogen-storage systems prohibit maintaining them as desirable sources of alternative hydrogen supply to the hydrogen-based power production systems during unavailability of the renewable energies. These concerns include, for example, inefficient bulk storage capacity of gaseous hydrogen and operational hazards pertaining to storage and distribution of liquid hydrogen. Such operational hazards may include, explosion of the liquid hydrogen from exposure to ambient environment.

[0004] Accordingly, there is a need in the related art for an effective system to implement a method for maintaining uninterrupted hydrogen-based power production utilizing intermittent renewable energy sources.

BRIEF DESCRIPTION

[0005] In accordance with one aspect of the present invention, a method for co-producing hydrogen and electrical power comprises utilizing an intermittent renewable energy source to generate energy for producing hydrogen and oxygen and subsequently transferring at least a portion of the energy to a production system to produce the hydrogen and the oxygen. The present technique further comprises channeling at least a portion of the hydrogen to a hydrogen-delivery system configured to deliver the hydrogen from the hydrogen-delivery system to at least one of a power generation system or a hydrogen-storage system and channeling at least a portion of the oxygen to an oxygen delivery system further configured to deliver the oxygen from the oxygen delivery system to a biomass gasification system. The biomass gasification system produces a synthesis gas by partial oxidation of a biomass feedstock. Further, this technique includes channeling at least a portion of the synthesis gas to the power generation system to produce electrical power therefrom.

[0006] According to another aspect of the present technique, a system for co-producing hydrogen and electrical power comprises an energy generating system for generating energy from an intermittent renewable energy source and a production system in energy communication with the energy generating system for producing hydrogen and oxygen. A hydrogen-delivery system is in fluid communication with the production system for receiving at least a portion of the hydrogen from the production system. The hydrogen-delivery system is further configured to channel at least a portion of the hydrogen to at least one of a power generation system or a hydrogen storage system. Further, an oxygen delivery system is in fluid communication with the production system for receiving at least a portion of the oxygen from the production system. The oxygen delivery system is further configured to channel at least a portion of the oxygen to a biomass gasification system. The biomass gasification system is configured to channel at least a portion of a synthesis gas to the power generation system.

DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] Fig. 1 is a diagrammatical representation of a system showing co-production hydrogen and power in accordance with one expression of the present technique;

[0009] Fig. 2 is another diagrammatical representation of a system showing co-production hydrogen and power in accordance with another expression of the present technique;

[0010] Fig. 3 is another diagrammatical representation of a system showing co-production hydrogen and power in accordance with another expression of the present technique; and

[0011] Fig. 4 is a diagrammatical representation of a biomass gasification process utilized for co-producing hydrogen and power in accordance with an expression of the present technique.

DETAILED DESCRIPTION

[0012] Currently, global energy infrastructure is rapidly transitioning from conventional "fossil fuel-based power production systems" to "hydrogen-based power production systems." These "fossil fuel-based power production systems" pose certain potential hazards to living organisms, such as, for example, environmental pollution, and global warming of earth's atmosphere. Hydrogen-based power production systems can substantially minimize those hazards because of their ability to produce relatively "clean energy." Moreover, it is significant to note that, energy security of nations might be threatened when their energy infrastructure is

predominantly dependent on fossil fuel-based energy, because these fossil fuel supplies are vulnerable to factors such as, limited natural reserves of those fossil fuels, geo-political and economic instabilities for example. Hydrogen-based power production systems can also effectively address these concerns, because adequate production and supply of hydrogen for the "hydrogen-based power production systems" may desirably be maintained utilizing certain renewable energy sources. These renewable energies include, without limitation, wind energy, solar energy and tidal energy. In implementation, maintaining uninterrupted renewable energy supply from renewable energy sources becomes a potential issue, because these renewable energies are intermittently available during a period when environmental conditions are favorable or appropriate for producing them.

[0013] Generally, in conventional approaches, alternative supply of hydrogen during non-availability of these renewable energies may be envisaged by transporting the hydrogen to the hydrogen-based power production systems from a hydrogen-storage system. In operation, certain concerns pertaining to these hydrogen-storage systems prohibit maintaining them a desirable source of alternative hydrogen supply to the hydrogen-based power production systems at unavailable period of those renewable energies. These concerns include, for example, inefficient bulk storage capacity of gaseous hydrogen due to its significantly low volumetric energy density compared to other conventional fuels. Although, compared to gaseous hydrogen, liquid hydrogen has relatively higher volumetric energy density to some extent, storage and distribution of the liquid hydrogen poses additional potential risks threatening operational safety of the hydrogen-based power production systems. These operational risks typically include, explosion caused due to boiling of the liquid hydrogen from its accidental exposure to ambient environment. Furthermore, liquefaction of gaseous hydrogen being implemented at a substantially low liquefaction temperature, typically in the range from about -200 °C to about -300 °C, feasibility of producing the liquid hydrogen from gaseous hydrogen becomes limited further, due to prohibitive manufacturing cost associated therewith.

[0014] As may be apparent from discussion in subsequent paragraphs that the present technique is designed to effectively respond to the abovementioned issues.

Fig. 1 depicts a system for co-producing hydrogen and power in accordance with one method expression of this technique. Current expression of this technique includes, a first step of utilizing an intermittent renewable energy source 10 by an energy generation system 101 to generate energy 102, including at least one of thermal energy or electrical energy. At a subsequent step, either a portion or all of the energy 102 produced by the energy generating system 101 is transferred to a production system 103. The production system 103 utilizes the energy 102 typically to dissociate water for producing hydrogen 104 and oxygen 107 therefrom. The hydrogen 104 produced by the production system 103 is further transferred to a hydrogen-delivery system 105. At a further step, the hydrogen-delivery system 105 delivers the hydrogen 104 to at least one of a power generation system 110 or a hydrogen-storage system 106.

[0015] In some embodiments, at least one portion of the oxygen 107 produced by the production system 103 is transported to an oxygen delivery system 130. The oxygen delivery system 130 transfers at least a portion of the oxygen 107 received from the production system 103 to a biomass gasification system 108. The oxygen 107 received by the biomass gasification system 108 induces thermo-chemical decomposition of a biomass feedstock 140. As a consequence thereof, the biomass feedstock 140 is partially oxidized to produce a synthesis gas 109. At a subsequent step, the synthesis gas 109 produced by the biomass gasification system 108 is transported to the power generation system 110. In operation, the synthesis gas 109 has combustible properties. Moreover this synthesis gas 109 has significant calorific value, for example, in the range from about 10 MJ/Nm^3 to about 20 MJ/Nm^3. The energy content of such combustible synthesis gas 109 is desirably converted to electrical power 115 in the power generation systems 110.

[0016] In some embodiments, the power generation systems 110 include typical hydrogen-based electricity production systems. Hence, during availability of renewable energies from the intermittent renewable energy sources 10, the power generation system 110 produces electrical power 115 utilizing at least a portion of the hydrogen 104 fuel delivered by the hydrogen-delivery system 105. Alternatively, at unavailable periods of the renewable energies, at least a portion of the synthesis gas

109 produced by the biomass gasification system 108 is transported to the power generation system 110 for producing electrical power 115 therefrom. Therefore, uninterrupted power supply 115 from the power generation systems 110 is ensured irrespective of availability of the renewable energies, duly avoiding undesirable hydrogen-storage. These power generation systems 110 include either a fuel cell-based power generation system or a micro-turbine-based power generation system or an internal combustion engine-based power generation system or a combination of all these systems. It may be appreciated that, in some embodiments, these power generation systems 110 are desirably adapted to utilize a fuel comprising an appropriate proportion of the hydrogen 104 transported from the hydrogen-delivery system 105 and at least a portion of the synthesis gas 109 transported from the biomass gasification system 108 for producing electrical power 115.

[0017] An exemplary biomass gasification process 200 employed by the biomass gasification system 108 for producing the synthesis gas 109 is depicted in Fig. 4. Generally, in such biomass gasification process 200, a fuel input, for example, an organic hydrocarbon-based biomass feedstock 140 undergoes partial thermo-chemical decomposition in presence of oxygen 107 to produce the synthesis gas 109. The synthesis gas 109 typically includes hydrogen (H_2), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2) and water vapor. Exemplary biomass feedstock 140 include, without limitation, industrial wastes; agricultural wastes, such as straws and husks; municipal wastes; organic wastes, such as animal husbandry by-products; energy crops, such as sugar cane; and suitable combinations of all these. It may be appreciated that, selecting fuels for the biomass gasification system 108 depends on trade off relationships among various factors pertaining to properties of these biomass feedstock 140, such as, energy content, ash content, moisture content, volatile matter content, particle size and bulk density, for example.

[0018] Operationally, as depicted in Fig. 4, the biomass gasification process 200 at a first step typically includes, a moisture removal process 208 to substantially remove moisture content of the biomass feedstock 140 for obtaining a relatively dry biomass feedstock 141. In a subsequent pyrolysis process 209, this dry biomass

feedstock 141 undergoes anaerobic thermal decomposition at exemplary temperature range from about 500 °C to about 800 °C to form a pyrolyzed mixture 210. The pyrolyzed mixture 210 generally includes solid substances, for example, charcoal; liquid substances, for example, pyrolignious oil and gaseous substances, for example, hydrogen and carbon monoxide. Further, a partial oxidation process 211 induced by the oxygen 107 partially oxidizes the pyrolyzed mixture 210 partially to form a partially oxidized mixture 212. This partially oxidized mixture 212 includes carbon dioxide (CO_2) and steam. The partial oxidation process 211 is generally characterized by a series of exemplary exothermic chemical transformations appended below.

$$C + O_2 \rightarrow CO_2 + \Delta \text{ (heat)}$$

$$H_2 + \tfrac{1}{2} O_2 \rightarrow H_2O + \Delta \text{ (heat)}$$

[0019] It is appropriate to mention that, thermal energy generated during the partial oxidation process 211 maintains desirable thermal environment of the biomass gasification systems 108 to sustain overall chemical kinetics of the biomass gasification process 200. Further, the oxidized mixture 212 undergoes a series of heterogeneous anaerobic chemical transformations (i.e. without being induced by oxygen) in a reduction process 213 to release the synthesis gas 109. The synthesis gas 109 is the final output derived from the biomass gasification process 200 deployed by the biomass gasification system 108. These heterogeneous chemical transformations of the oxidized mixture 212 include certain exothermic as well as endothermic chemical reactions. Some exemplary chemical transformations representing the reduction process 213 are appended below.

$$CO_2 + C \rightarrow 2CO - \Delta \text{ (heat)}$$

$$C + H_2O \rightarrow CO + H_2 - \Delta \text{ (heat)}$$

$$CO_2 + H_2 \rightarrow CO + H_2O + \Delta \text{ (heat)}$$

$$C + 2H_2 \rightarrow CH_4 + \Delta \text{ (heat)}$$

[0020] Certain alternative embodiments pertaining to configuration of the biomass gasification system 108 include at least one of a fixed bed biomass gasification system or a fluidized bed biomass gasification system. From constructional perspectives, the fixed bed biomass gasification systems are characterized by at least one stationary gasification reaction zone structurally supported by grates. On the other hand, the fluidized bed biomass gasification systems include reaction zones typically comprising a moving or circulating bed constructed from chemically inert bed materials, for example, sand. Selecting a suitable configuration of the biomass gasification systems 108 depends on trade-off relationships among various factors, such as, desired power output capacity of the power generation systems 110, typical characteristic properties of the synthesis gas 109 released from these gasification systems, including calorific value, particulate matter content and tar content thereof, ease of manufacturing of these gasification systems, for example. Generally, flow turbulence induced in the bed material constructing the moving or circulating bed of the fluidized bed gasification systems, promotes relatively uniform thermo-chemical mixing of reactants during various steps of the biomass gasification process 200 to ensure enhanced power output capacity of the power generation system 110, but at the expense of comparatively more adverse environmental impact of the synthesis gas 109 released from these gasification systems due to increased particulate matter content of these synthesis gas 109.

[0021] In some embodiments, at least a portion of the synthesis gas 109 produced by the biomass gasification system 108 is desirably transported to a hydrogen-reforming system 112 for reforming hydrogen 104. In present embodiments, the hydrogen 104 reformed in the hydrogen-reforming system 112 is desirably transported to the hydrogen-delivery system 105. Operationally, the hydrogen-reforming system 112 employs water gas shift reaction process typically at a temperature range from about 150 °C to about 450 °C. In implementation, the hydrogen 104 is reformed from carbon monoxide (CO) content of the synthesis gas 109 in presence of some catalyst, for example, ferrous oxide (Fe_3O_4). Exemplary water gas shift reaction process may be represented as appended below.

$$CO_{(g)} + H_2O_{(g)} \xrightarrow{Fe_3O_4} CO_{2\,(g)} + H_{2\,(g)}$$

[0022] In some other embodiments, the hydrogen-delivery system 105 further delivers at least a portion of the hydrogen 104 received from the systems 103, 112 to a hydrogen-storage system 106. Hydrogen 104 stored in the hydrogen-storage system 106 may be optionally consumed by certain other adjacent hydrogen-based systems (not shown) that do not pertain to the hydrogen-based electricity production, for example, fuel refilling system for hydrogen-based automobiles.

[0023] Fig. 2 depicts another system for co-producing hydrogen and power in accordance with another method expression of this technique. In the current expression, the hydrogen-delivery system 105 delivers all of the hydrogen 104 received from the systems 103, 112 to the hydrogen-based electricity production system 110 for producing electrical power 115 therefrom. Therefore, in accordance with this embodiment, uninterrupted power supply 115 at unavailable periods of renewable energies is desirably maintained by transferring hydrogen 104 from the hydrogen reforming system 112 to the hydrogen-delivery system 105 that further delivers all of the hydrogen 104 to the hydrogen-based electricity production systems 110 for generating electrical power 115. Another alternative system according to some other method expression of this technique is depicted in Fig. 3. In this expression, the power generation system 110 receives all of the synthesis gas 109 produced by the biomass gasification system 108. Additionally, in present expression, the hydrogen-delivery system 105 desirably delivers all of the hydrogen 104 received from the systems 103, 112 to the power generation system 110.

[0024] In operation, the production system 103 is typically a hydro-splitting system that dissociates water to produce hydrogen 104 and oxygen 107 therefrom. Various alternative embodiments of these production systems 103 may be envisioned depending on trade-off relationships among factors, such as, for example, overall efficiency, cost-effectiveness and simplicity to design and operate those systems. These production systems 103 typically include, without limitation, an electrolysis system, a thermal splitting system, an electro-thermal splitting system, a thermo-

chemical splitting system, a photo-chemical splitting system, a photo-electrochemical splitting system and combinations of all these systems.

[0025] Briefly, in an exemplary embodiment, the electrical energy output produced from the energy generating system 101 is employed by the typical electrolysis system that dissociates water to release the hydrogen 104 and the oxygen 107. The electrical energy required to perform the electrolysis may be generated from the energy generating system 101 in various ways. For example, in photo-electrochemical splitting systems this electrical energy is obtained by absorption of solar photons in semiconductor-based systems. On the other hand, in photo-chemical splitting systems, a chemical sensitizer, for example, ethylenediamine tetraacetic acid (EDTA) absorbs solar photons to release electrochemical energy to drive the hydro-splitting system for producing the hydrogen 104 and the oxygen 107. Some other embodiments of those production systems 103 include, for example, a thermal splitting system that utilizes thermal energy output generated by the energy generating system 101 to dissociate water. In another embodiment, an electro-thermal splitting system utilizes thermal energy output coupled with electrical energy output generated by the energy generating system 101 to perform the hydro-splitting. In other alternative embodiment, a thermo-chemical splitting system utilizes thermal energy output of the energy generating system 101 in presence of certain chemicals, for example, bromine and iodine to split water, producing hydrogen 104 and oxygen 107.

[0026] In conformation with the alternative method expressions implemented by the systems for co-producing hydrogen and power (shown in Fig.1 through Fig. 3), it may be appreciated that a typical system for co-producing hydrogen and electrical power includes an energy generating system 101 for generating energy 102 from an intermittent renewable energy source 10 and a production system 103 in energy communication with the energy generating system 101 for producing hydrogen 104 and oxygen 107. A hydrogen-delivery system 105 is in fluid communication with the production system 103 for receiving at least a portion of the hydrogen 104 from the production system 103. The hydrogen-delivery system 105 is further configured to channel at least a portion of the hydrogen 104 to at least one of a power generation system 110 or a hydrogen storage system 106. Further, an oxygen delivery system

130 is in fluid communication with the production system 103 for receiving at least a portion of the oxygen 107 from the production system 103. The oxygen delivery system 130 is further configured to channel at least a portion of the oxygen 107 to a biomass gasification system 108. The biomass gasification system 108 is configured to channel at least a portion of a synthesis gas 109 to the power generation system 110. It is appropriate to mention that, alternative embodiments of the subsystems building the system for co-producing hydrogen and electrical power are identical to those described in preceding paragraphs.

[0027] It will be apparent to those skilled in the art that, although the invention has been illustrated and described herein in accordance with the patent statutes, modification and changes may be made to the disclosed embodiments without departing from the true spirit and scope of the invention. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit and scope of the invention.